

Mucool - Linac facility- Heat exchanger sizing

cd 03/28/02 Fermilab

Goal

This program permits us to determine the size of the HX to be used for the mucool linac cooling chamber.

Note- assumption:

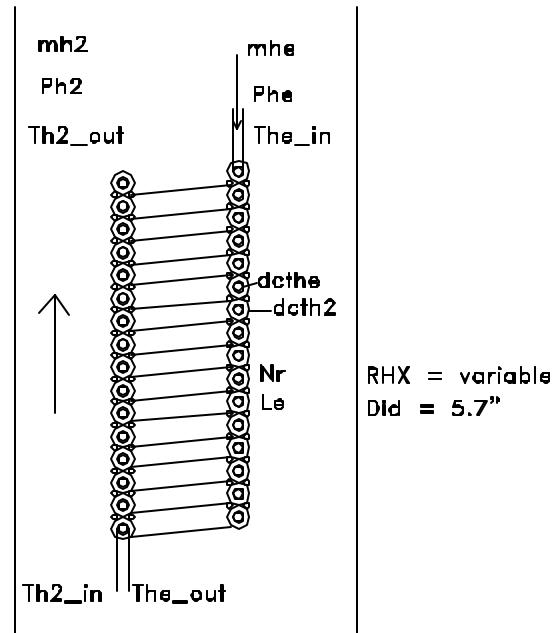
- Heat exchange: Helium/LH₂ counter-current flow
- Number of iteration = 1000
- Reduction diameter = 2 "

Parameters

- Power to extract from the absorber Q=500 W
- Temperature in/out He loop T_{hein}=14 K T_{heout}=18 K
- Temperature in/out H₂ loop T_{H2in}=18 K T_{H2out}=17 K
- Pressure He/H₂ P_{he}=0.2 MPa P_{H2}=0.121 MPa
- Mass-flow He/H₂ m_{he}=27 g/s m_{H2}=63 g/s
- Helium properties (Hepak)

Schematic

- Inner diam. cooling tube = 0.555 inch
- Thickness = 0.035 inch



Results

1- Surface of the heat exchange

SurfaceHX=0.2492 m²

2- Length for dct_id=0.555 inch

L_e=6.6 m

3- If DHX=3.5 inch and dct =5/8 inch (id0.555)than

Nr = 22 spires and L_{e2}=6.6 m

4- Pressure drop in HX2

drop~4E-4

5- Pressure drop in He

drop= 2.1 psi

6- Heat transfer coeff.

h= 0.17W/cm²*K

Comments: Fine for 500 W to remove at 17 K, with DT=1K. Outer sheet: PIS 5 SCh5, L=20"

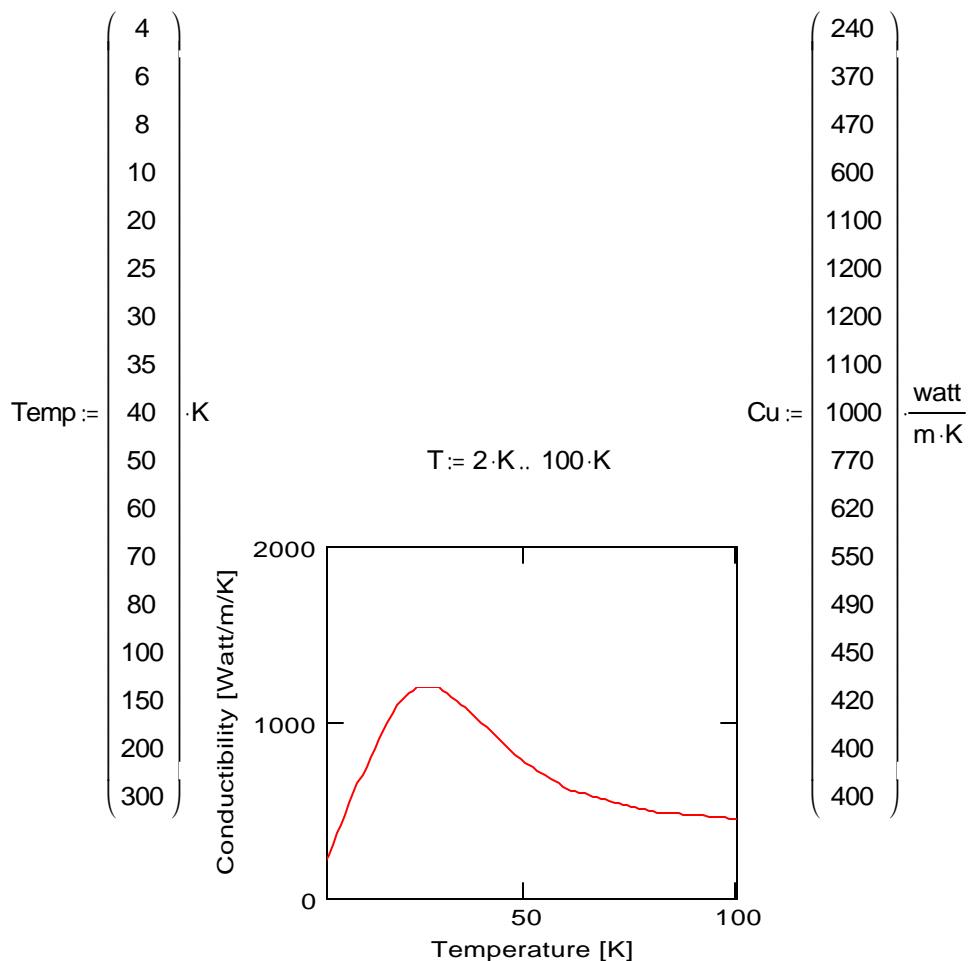
1. MATERIAL PROPERTIES

1.1. Thermal conductivity of copper

Data from file: CONDUC95.xls

Linear Interpolation

$$k_{Cu}(T) := \text{interp}(\text{Temp}, Cu, T)$$



1.2. Specific Heat of supercritical He at 2 bar

Data from HEPAK

$$\text{Temp} := Y^{(1)} \cdot K$$

$$Y := \text{READPRN}("He_2bar.prn")$$

$$cp_{He} := Y^{(5)} \frac{\text{joule}}{\text{kg} \cdot \text{K}}$$

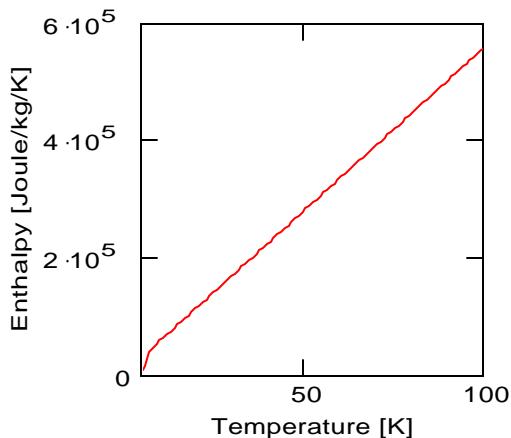
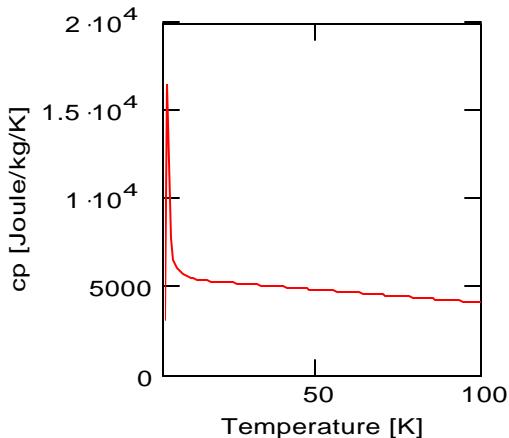
$$T := 4..100$$

$$H_{He} := Y^{(6)} \frac{\text{joule}}{\text{kg}}$$

$$cp_{He}(T) := \text{interp}(\text{Temp}, cp_{He}, T)$$

$$H_{He}(T) := \text{interp}(\text{Temp}, H_{He}, T)$$

$$cp_{He}(4.6 \cdot K) = 5.984 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$$



$T := 0 \text{ K} .. 300 \text{ K}$

density	viscosity	conductivity	specific heat	enthalphy
$\rho_{\text{He}} := Y^{(2)} \frac{\text{kg}}{\text{m}^3}$	$\mu_{\text{He}} := Y^{(3)} \frac{\text{Pa} \cdot \text{sec}}{\text{Pa} \cdot \text{sec}}$	$k_{\text{He}} := Y^{(4)} \frac{\text{watt}}{\text{m} \cdot \text{K}}$	$c_{\text{pHe}} := Y^{(5)} \frac{\text{joule}}{\text{kg} \cdot \text{K}}$	$H_{\text{He}} := Y^{(6)} \frac{\text{joule}}{\text{kg}}$
$\rho_{\text{He}}(T) := \text{linterp}(\text{Temp}, \rho_{\text{He}}, T)$		$\rho_{\text{He}}(65 \text{ K}) = -6.432 \text{ kg m}^{-3}$		
$\mu_{\text{He}}(T) := \text{linterp}(\text{Temp}, \mu_{\text{He}}, T)$			$\mu_{\text{He}}(65 \text{ K}) = 8.571 \times 10^{-6} \text{ kg m}^{-1} \text{ sec}^{-1}$	
$k_{\text{He}}(T) := \text{linterp}(\text{Temp}, k_{\text{He}}, T)$			$k_{\text{He}}(65 \text{ K}) = 0.062 \text{ m}^{-1} \text{ K}^{-1} \text{ watt}$	
$c_{\text{pHe}}(T) := \text{linterp}(\text{Temp}, c_{\text{pHe}}, T)$			$c_{\text{pHe}}(65 \text{ K}) = 4.631 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$	
$H_{\text{He}}(T) := \text{linterp}(\text{Temp}, H_{\text{He}}, T)$			$H_{\text{He}}(19.477 \text{ K}) = 1.153 \times 10^5 \text{ kg}^{-1} \text{ joule}$	

1.3. Specific Heat of supercritical Hydrogen at 1.21bar Data from GASPAK

$Yh2 := \text{READPRN}("H2_1bar21.prn")$

$$\text{Temp} := Yh2^{(1)} \text{ K}$$

$$cpH2 := Yh2^{(5)} \frac{\text{joule}}{\text{kg} \cdot \text{K}}$$

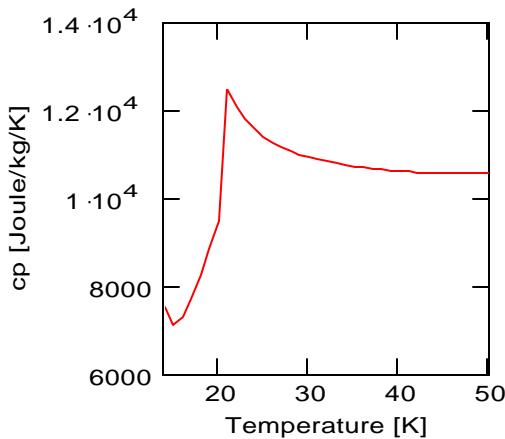
$$cpH2(T) := \text{linterp}(\text{Temp}, cpH2, T)$$

$$cpH2(14 \text{ K}) = 7.516 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$$

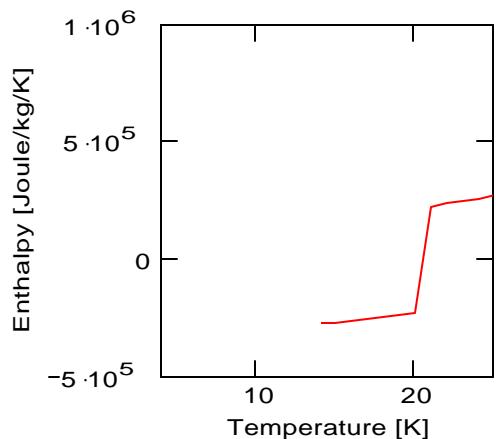
$$T := 14 .. 50$$

$$HH2 := Yh2^{(6)} \frac{\text{joule}}{\text{kg}}$$

$$HH2(T) := \text{linterp}(\text{Temp}, HH2, T)$$



$$T := 0 \text{ K} .. 300 \text{ K}$$



density	viscosity	conductivity	specific heat	enthalphy
$\rho_{\text{H2}} := Yh2^{(2)} \frac{\text{kg}}{\text{m}^3}$	$\mu_{\text{H2}} := Yh2^{(3)} \frac{\text{Pa} \cdot \text{sec}}{\text{Pa} \cdot \text{sec}}$	$k_{\text{H2}} := Yh2^{(4)} \frac{\text{watt}}{\text{m} \cdot \text{K}}$	$c_{\text{pH2}} := Yh2^{(5)} \frac{\text{joule}}{\text{kg} \cdot \text{K}}$	$H_{\text{H2}} := Yh2^{(6)} \frac{\text{joule}}{\text{kg}}$
$\rho_{\text{H2}}(T) := \text{linterp}(\text{Temp}, \rho_{\text{H2}}, T)$			$\rho_{\text{H2}}(65 \text{ K}) = 0.41 \text{ kg m}^{-3}$	
$\mu_{\text{H2}}(T) := \text{linterp}(\text{Temp}, \mu_{\text{H2}}, T)$			$\mu_{\text{H2}}(65 \text{ K}) = 3.054 \times 10^{-6} \text{ kg m}^{-1} \text{ sec}^{-1}$	
$k_{\text{H2}}(T) := \text{linterp}(\text{Temp}, k_{\text{H2}}, T)$			$k_{\text{H2}}(65 \text{ K}) = 0.047 \text{ kg m sec}^{-3} \text{ K}^{-1}$	
$c_{\text{pH2}}(T) := \text{linterp}(\text{Temp}, c_{\text{pH2}}, T)$			$c_{\text{pH2}}(65 \text{ K}) = 1.057 \times 10^4 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$	
$H_{\text{H2}}(T) := \text{linterp}(\text{Temp}, H_{\text{H2}}, T)$			$H_{\text{H2}}(65 \text{ K}) = 6.973 \times 10^5 \text{ kg}^{-1} \text{ joule}$	

2. DATA - input

$$Q := 500 \cdot \text{watt}$$

$$imax := 1000$$

$$mdothe := 27 \cdot 10^{-3} \frac{\text{kg}}{\text{sec}}$$

$$mdoth2 := 63 \cdot 10^{-3} \frac{\text{kg}}{\text{sec}}$$

2.1. choose a set of temperatures:

$$\text{Thein} := 14 \cdot \text{K}$$

$$\text{Th2in} := 18 \cdot \text{K}$$

$$\text{Theout} := 17.5 \cdot \text{K}$$

$$\text{Th2out} := 17 \cdot \text{K}$$

2.2. Geometry

a) HX lenght - Solution 1

$$Nr := 22$$

Number of spires

$$DHX := 3.5 \cdot \text{in}$$

$$RHX := \frac{DHX}{2}$$

$$Le := 2 \cdot \pi \cdot RHX \cdot Nr$$

$$Le = 6.144 \text{ m}$$

Solution 2

$$Nr2 := 22$$

Number of spires

$$DHX2 := 3.5 \cdot \text{in}$$

$$RHX2 := \frac{DHX2}{2}$$

$$Le2 := 2 \cdot \pi \cdot RHX2 \cdot Nr2$$

$$Le2 = 6.144 \text{ m}$$

b) Hx cooling spire

$$dcthe := 0.555 \cdot 25.4 \cdot \text{mm}$$

cooling tube inner diameter

$$dcthe = 14.097 \text{ mm}$$

$$thct := 0.035 \cdot 25.4 \cdot \text{mm}$$

wall thickness of cooling tube -

Any thickness would fit
if Q_c is very large..

$$thct = 0.889 \text{ mm}$$

$$dcth2 := dcthe + 2 \cdot thct$$

cooling tube outer diameter

$$dctheout := dcth2$$

c) HX - outer shell

$$Did := 5.295 \cdot \text{in}$$

$$Dred := 2 \cdot \text{in}$$

$$AH2 := 3.14 \cdot \left[\left(\frac{Did - 2 \cdot \frac{5 \cdot \text{in}}{8}}{8} \right)^2 - Dred^2 \right]$$

$$AH2 = 6.261 \times 10^{-3} \text{ m}^2$$

$$Per := 3.14 \cdot (Did + Dred)$$

$$DHXh := 4 \cdot \frac{AH2}{Per}$$

Hydraulic diameter: $DHXh = 0.043 \text{ m}$

$$LHX := 15 \cdot \text{in}$$

$$Acthe := \pi \cdot \left(\frac{dcthe}{2} \right)^2$$

cross-section area He

$$Acthe = 1.561 \times 10^{-4} \text{ m}^2$$

$$Ah2 := \left[\pi \cdot \left(\frac{DHXh}{2} \right)^2 \right]$$

cross-section area H2

$$Ah2 = 1.455 \times 10^{-3} \text{ m}^2$$

Determine the lenght of the HX for Nr spires

$$Scthe := \pi \cdot dcthe \cdot Le \quad \text{inner surface area cooling tube}$$

$$Scth2 := \pi \cdot dcth2 \cdot Le \quad \text{outer surface area cooling tube}$$

$$Lhx := Nr \cdot dcth2$$

$$Lhx = 13.75 \text{ in}$$

$$Scthe = 0.272 \text{ m}^2$$

$$Scth2 = 0.306 \text{ m}^2$$

3. COOLING SCHEME:

3.1. Forced convection heat transfer coefficients (turbulent flow)

$$\text{Pr}(\mu, \text{cp}, k, T) := \mu(T) \cdot \frac{\text{cp}(T)}{k(T)}$$

Prandtl number

$$\text{Re}(\rho, v, d, \mu, T) := \rho(T) \cdot v \cdot \frac{d}{\mu(T)}$$

Reynolds number

$$\text{Nuh2}(\text{Re}) := 0.083 \cdot \text{Re}^{0.85}$$

Nusselt number - hydrogen - shell side

$$\text{Nu}(\text{Re}, \text{Pr}) := 0.023 \cdot \text{Re}^{0.8} \cdot \text{Pr}^{0.4}$$

Nusselt number - helium -inner side

$$h(\text{Nu}, k, T, d) := \text{Nu} \cdot \frac{k(T)}{d}$$

convection heat transfer coefficient
for natural convection in monophasic
He

3.2. Helium flow velocities

$$\text{mdothe} = 0.027 \text{ kg sec}^{-1}$$

He mass flow rate

$$v\text{He}_i := \frac{\text{mdothe}}{\text{Acthe} \cdot \rho\text{He}(\text{The}_i)}$$

$v\text{He}_i$

$$\text{Prhe}_i := \text{Pr}(\mu\text{He}, \text{cpHe}, k\text{He}, \text{The}_i)$$

Prhe

$$\text{Rehe}_i := \text{Re}(\rho\text{He}, v\text{He}_i, \text{dcthe}, \mu\text{He}, \text{The}_i)$$

Rehe

$$\text{Nuhe}_i := \text{Nu}(\text{Rehe}_i, \text{Prhe}_i)$$

Nuhe

$$h\text{cthe}_i := h(\text{Nuhe}_i, k\text{He}, \text{The}_i, \text{dcthe})$$

$h\text{cthe}$

$$\text{The}_i := \text{Thein} + i \cdot \frac{(\text{Theout} - \text{Thein})}{\text{imax}}$$

$$\text{mdothe} = 0.027 \text{ kg sec}^{-1}$$

$$\text{Acthe} = 1.561 \times 10^{-4} \text{ m}^2$$

$$\text{Prhe}_{1000} = 0.731$$

$$\text{Rehe}_{1000} = 7.323 \times 10^5$$

$$\text{Acthe} = 1.561 \times 10^{-4} \text{ m}^2$$

$$\text{The}_{1000} = 17.5 \text{ K}$$

$$\text{dcthe} = 0.014 \text{ m}$$

$$v\text{He}_{1000} = 31.285 \text{ m sec}^{-1}$$

3.3. Hydrogen flow velocities

$$\text{mdoth2} = 0.063 \text{ kg sec}^{-1}$$

Hydrogen mass flow rate

$$v\text{H2}(m, A, \rho, T) := \frac{m}{A \cdot \rho(T)}$$

$$v\text{H2}_i := v\text{H2}(\text{mdoth2}, \text{Ah2}, \rho\text{H2}, \text{Th2}_i)$$

$v\text{H2}$

$$\text{Th2}_i := \text{Th2out} - \left[i \cdot \frac{(\text{Th2out} - \text{Th2in})}{\text{imax}} \right]$$

$$\text{Prh2}_i := \text{Pr}(\mu\text{H2}, \text{cpH2}, k\text{H2}, \text{Th2}_i)$$

Prh2

$$\text{Reh2}_i := \text{Re}(\rho\text{H2}, v\text{H2}_i, \text{dcth2}, \mu\text{H2}, \text{Th2}_i)$$

Reh2

$$\text{Nuh2}_i := \text{Nuh2}(\text{Reh2}_i)$$

Nuh2

$$h\text{cth2}_i := h(\text{Nuh2}_i, k\text{H2}, \text{Th2}_i, \text{dcth2})$$

$h\text{cth2}$

$$\text{mdoth2} = 0.063 \text{ kg sec}^{-1}$$

$$\text{Ah2} = 1.455 \times 10^{-3} \text{ m}^2$$

$$\text{Reh2}_{1000} = 4.108 \times 10^4$$

3.4. Calculation of the wall temperature

$$T_{cti} := \frac{[(The_i \cdot hcthe_i) + (Th2_i \cdot hcth2_i)]}{(hcthe_i + hcth2_i)}$$
The_i Th2_i Tct_i

3.5. Convection in helium

$$Scthe_i := \frac{\frac{Q}{imax}}{hcthe_i \cdot (Tct_i - The_i)}$$
Scthe_i

3.6. Convection in hydrogen

$$Scth2_i := \frac{\frac{Q}{imax}}{(-hcth2)_i \cdot (Tct_i - Th2_i)}$$
Scth2_i

3.7. Calculation of the HX surface and lenght

$$SurfaceHX := \sum_i Scth2_i$$

$$dcthe = 0.014 \text{ m}$$

Surface of exchange

$$SurfaceHX = 0.29409 \text{ m}^2$$

$$L(d) := \frac{SurfaceHX}{\pi \cdot d}$$

Lenght of HX for dcthe

$$L(dcthe) = 6.64047 \text{ m}$$

4. Approach with the flux balance

4.1. Power to extract from the hydrogen

$$Ptot := \frac{Q}{Le2} \quad Ptot = 81.376 \text{ m}^{-1} \text{ watt}$$

$$Le2 = 6.144 \text{ m}$$

4.2. Solid conduction

$$Thein = 14 \text{ K}$$

$$Th2in = 18 \text{ K}$$

$$The := \frac{Thein + Theout}{2}$$

$$The = 15.75 \text{ K}$$

$$Theout = 17.5 \text{ K}$$

$$Th2out = 17 \text{ K}$$

$$Th2 := \frac{Th2in + Th2out}{2}$$

$$Th2 = 17.5 \text{ K}$$

$$TepsHe := 1.15 \text{ K}$$

$$Tcthe := The + TepsHe$$

$$Tcthe = 16.9 \text{ K}$$

$$TepsH2 := 0.19 \text{ K}$$

$$Tcth2 := Th2 + TepsH2$$

$$Tcth2 = 17.69 \text{ K}$$

$$thct = 8.89 \times 10^{-4} \text{ m}$$

$$Le = 6.144 \text{ m}$$

$$Scthe := \pi \cdot dcthe \cdot Le$$

$$Scthe = 0.272 \text{ m}^2$$

$$Scth2 := \pi \cdot dcth2 \cdot Le$$

$$Scth2 = 0.306 \text{ m}^2$$

heat conduction path though the wall thickness

$$Qs(Tcth2) := \frac{Scthe}{thct \cdot Le2} \cdot \int_{Tcthe}^{Tcth2} kCu(T) dT$$

$$Qs(Tcth2) = 3.797 \times 10^4 \text{ m}^{-1} \text{ watt}$$

$$Qs(Tcthe) = 0 \text{ m}^{-1} \text{ watt}$$

$$DT := \frac{(thct \cdot Ptot \cdot Le2)}{Scthe \cdot (kCu(Tcth2) - kCu(Tcthe))} \quad kCu(Tcthe) = 945 \text{ m}^{-1} \text{ K}^{-1} \text{ watt}$$

$$kCu(Tcth2) = 984.5 \text{ m}^{-1} \text{ K}^{-1} \text{ watt}$$

$$\int_{Tcthe}^{Tcth2} kCu(T) dT = 762.153 \text{ m}^{-1} \text{ watt}$$

$$DT = 0.041 \text{ K}$$

$$(kCu(Tcth2) - kCu(Tcthe)) \cdot (Tcth2 - Tcthe) = 31.205 \text{ m}^{-1}$$

4.3. Helium Cooling Capacity

$$\rho_{He}(mdothe, Theout, Thein) := \frac{[mdothe \cdot cpHe(The) \cdot (Theout - Thein)]}{Le2}$$

$$\rho_{He}(mdothe, Theout, Thein) = 82.718 \text{ m}^{-1} \text{ watt}$$

4.4. Hydrogen Cooling Capacity

$$\rho_{H2}(mdoth2, Th2out, Th2in) := \frac{[mdoth2 \cdot (HH2(Th2out) - HH2(Th2in))]}{Le2}$$

$$\rho_{H2}(mdoth2, Th2out, Th2in) = 18.201 \text{ m}^{-1} \text{ watt}$$

4.5. Convection in helium

$$\rho_{He} := \rho_{He}(Tcthe)$$

$$\rho_{He} = 5.734 \text{ kg m}^{-3}$$

$$dcthe = 0.014 \text{ m}$$

$$\mu_{He} := \mu_{He}(Tcthe)$$

$$\mu_{He} = 3.257 \times 10^{-6} \text{ sec}^2 \text{ m}^{-3} \text{ watt}$$

$$Tcthe = 16.9 \text{ K}$$

$$v_{He} := \frac{mdothe}{Acthe \cdot \rho_{He}}$$

$$v_{He} = 30.172 \text{ m sec}^{-1}$$

$$cp_{He} := cp_{He}(Tcthe)$$

$$cp_{He} = 5.353 \times 10^3 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$$

$$k_{He} := k_{He}(Tcthe)$$

$$k_{He} = 0.024 \text{ kg m sec}^{-3} \text{ K}^{-1}$$

$$Re_{He}(\rho, v, d, \mu) := \rho \cdot v \cdot \frac{d}{\mu}$$

$$Re_{He} := Re_{He}(\rho_{He}, v_{He}, dcthe, \mu_{He})$$

$$Re_{He} = 7.487 \times 10^5$$

$$Pr_{He}(\mu, cp, k) := \mu \cdot \frac{cp}{k}$$

$$Pr_{He} := Pr_{He}(\mu_{He}, cp_{He}, k_{He})$$

$$Pr_{He} = 0.731$$

$$Nu(Re, Pr) := 0.023 \cdot Re^{0.8} \cdot Pr^{0.4}$$

$$Nu_{He} := Nu(Re_{He}, Pr_{He})$$

$$Nu_{He} = 1.016 \times 10^3$$

$$h(Nu, k, d) := Nu \cdot \frac{k}{d}$$

$$hc_{the} := h(Nu_{He}, k_{He}, dcthe)$$

$$hc_{the} = 1.718 \times 10^3 \text{ m}^{-2} \text{ K}^{-1} \text{ watt}$$

$$Qc(The, Tcthe) := \frac{Scthe \cdot hc_{the} \cdot (Tcthe - The)}{Le2}$$

$$Qc(The, Tcthe) = 87.507 \text{ m}^{-1} \text{ watt}$$

$$Tcthe = 16.9 \text{ K}$$

4.6. Convection in hydrogen

$$\rho_{H2} := \rho_{H2}(Tcth2)$$

$$\rho_{H2} = 73.61 \text{ kg m}^{-3}$$

$$dcth2 = 0.016 \text{ m}$$

$$\mu_{H2} := \mu_{H2}(Tcth2)$$

$$\mu_{H2} = 1.72 \times 10^{-5} \text{ sec}^2 \text{ m}^{-3} \text{ watt}$$

$$Tcth2 = 17.69 \text{ K}$$

$$v_{H2} := \frac{mdoth2}{Ah2 \cdot \rho_{H2}}$$

$$v_{H2} = 0.588 \text{ m sec}^{-1}$$

$$cp_{H2} := cp_{H2}(Tcth2)$$

$$cp_{H2} = 8.06 \times 10^3 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$$

$$k_{H2} := k_{H2}(Tcth2)$$

$$k_{H2} = 0.1 \text{ kg m sec}^{-3} \text{ K}^{-1}$$

$$Reh2(\rho, v, d, \mu) := \rho \cdot v \cdot \frac{d}{\mu}$$

$$Reh2 := Reh2(\rho_{H2}, v_{H2}, dcth2, \mu_{H2})$$

$$Reh2 = 3.996 \times 10^4$$

$$Prh2(\mu, cp, k) := \mu \cdot \frac{cp}{k}$$

$$Prh2 := Prh2(\mu_{H2}, cp_{H2}, k_{H2})$$

$$Prh2 = 1.384$$

$$Nuh2(Re) := 0.083 \cdot Re^{0.85}$$

$$Nuh2 := Nuh2(Reh2)$$

$$Nuh2 = 676.778$$

$$h(Nu, k, d) := Nu \cdot \frac{k}{d}$$

$$hc_{th2} := h(Nuh2, k_{H2}, dcth2)$$

$$hc_{th2} = 4.105 \times 10^3 \text{ m}^{-2} \text{ K}^{-1} \text{ watt}$$

$$Qch2(Th2, Tcth2) := \frac{Scth2 \cdot hc_{th2} \cdot (Tcth2 - Th2)}{Le2}$$

$$Qch2(Th2, Tcth2) = 40.456 \text{ m}^{-1} \text{ watt}$$

$$Tcth2 = 17.69 \text{ K}$$

4.7. Pressure drop

$$f := 0.003$$

In helium circuit

$$Re_{he} = 7.487 \times 10^5$$

$$f_{he} := 0.00332 + \frac{0.221}{Re_{he}} - \frac{0.237}{Re_{he}^2}$$

turbulent

$$dc_{the} = 0.014 \text{ m}$$

The

$$f_{he} = 0.012$$

$$\Delta p = 1.397 \times 10^4 \text{ Pa}$$

$$\Delta p = 2.025 \text{ psi}$$

$$\Delta p = f_{he} \frac{L_{he} \cdot \rho_{He} \cdot v_{He}^2}{dc_{the} \cdot 2}$$

$\rho_{He} = 5.734 \text{ kg m}^{-3}$
 $v_{He} = 30.172 \text{ m sec}^{-1}$

$$L_{he} = 6.144 \text{ m}$$

$$f_{he} = \frac{L_{he} \cdot \rho_{He} \cdot v_{He}^2}{dc_{the} \cdot 2}$$

$DH_{th} = 0.043 \text{ m}$

$$\Delta p_2 = 1.397 \times 10^4 \text{ Pa}$$

$$\Delta p_2 = 2.025 \text{ psi}$$

In Hydrogen circuit

$$Re_{H2} = 3.996 \times 10^4$$

$$f_{H2} := \frac{1}{(1.8 \cdot \log(Re_{H2}) - 1.64)^2}$$

Blasius equation $Re < 10^5$

$$f_{H2} = 0.023$$

$$\Delta p_{H2} := f_{H2} \frac{L_{H2} \cdot \rho_{H2} \cdot v_{H2}^2}{DH_{th} \cdot 2}$$

$\rho_{H2} = 73.61 \text{ kg m}^{-3}$
 $v_{H2} = 0.588 \text{ m sec}^{-1}$

$L_{H2} = 0.381 \text{ m}$
 $DH_{th} = 0.043 \text{ m}$

$$\Delta p_{H2} = 2.554 \text{ Pa}$$

$$\Delta p_{H2} = 3.705 \times 10^{-4} \text{ psi}$$

4.8. RESULTS

$$Q_c(\text{The}, T_{c_{the}}) = 87.507 \text{ m}^{-1} \text{ watt}$$

$$Q = 500 \text{ watt}$$

$$P_{tot} = 81.376 \text{ m}^{-1} \text{ watt}$$

The Q_s is larger than Q_i - any thickness of the copper cooling tube would fit - this parameter is not a limitation

$$Q_s(T_{c_{th2}}) = 3.797 \times 10^4 \text{ m}^{-1} \text{ watt}$$

$$Q_s(T_{c_{the}}) = 0 \text{ m}^{-1} \text{ watt}$$

$$Q_{ch2}(\text{Th}_2, T_{c_{th2}}) = 40.456 \text{ m}^{-1} \text{ watt}$$

$$Q_s(T)$$

$$Q_c(\text{The}, T)$$

$$P_{tot}$$

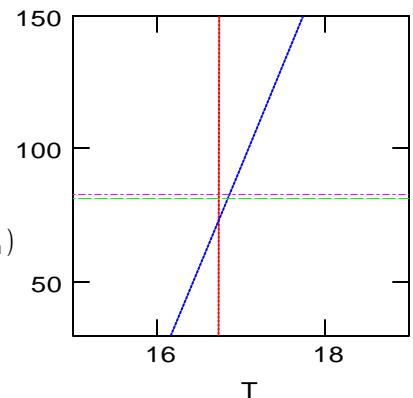
$$P_{tot}$$

$$p_{He}(m_{d0} \text{the}, \text{Theout}, \text{Thein})$$

$$p_{H2}(m_{d0} \text{th2}, \text{Th2out}, \text{Th2in}) = 82.027 \text{ m}^{-1} \text{ watt}$$

$$T := 4 \cdot K .. 200 \cdot K$$

$$p_{He}(m_{d0} \text{the}, \text{Theout}, \text{Thein})$$



SUMMARY

$$Q = 500 \text{ watt}$$

$$P_{\text{tot}} = 81.376 \text{ m}^{-1} \text{ watt}$$

$$\text{SurfaceHX} = 0.29409 \text{ m}^2$$

$$L(\text{dcthe}) = 6.64 \text{ m}$$

$$D_{\text{red}} = 2 \text{ in}$$

Helium

$$T_{\text{hein}} = 14 \text{ K}$$

$$T_{\text{he}} = 15.75 \text{ K}$$

$$S_{\text{cthe}} = 0.272 \text{ m}^2$$

$$m_{\text{dothe}} = 0.027 \text{ kg sec}^{-1}$$

$$T_{\text{heout}} = 17.5 \text{ K}$$

$$m_{\text{dothe}} = 0.027 \text{ kg sec}^{-1}$$

$$\text{drop} = 1.397 \times 10^4 \text{ Pa}$$

$$\text{drop} = 2.025 \text{ psi}$$

$$\text{drop2} = 1.397 \times 10^4 \text{ Pa}$$

$$\text{drop2} = 2.025 \text{ psi}$$

Hydrogen

$$T_{\text{H2in}} = 18 \text{ K}$$

$$T_{\text{H2}} = 17.5 \text{ K}$$

$$S_{\text{cth2}} = 0.306 \text{ m}^2$$

$$m_{\text{dot2}} = 0.063 \text{ kg sec}^{-1}$$

$$T_{\text{H2out}} = 17 \text{ K}$$

$$\text{drop}_{\text{H2}} = 2.554 \text{ Pa}$$

$$\text{drop}_{\text{H2}} = 3.705 \times 10^{-4} \text{ psi}$$

$$m_{\text{dot2}} = 0.063 \text{ kg sec}^{-1}$$

Proposal for the HX design, Nr number of spire, RHX, radius

$$DHX = 3.5 \text{ in}$$

$$Nr = 22$$

$$RHX = 0.044 \text{ m}$$

$$Le = 6.144 \text{ m}$$

$$\text{drop} = 2.025 \text{ psi}$$

$$DHX2 = 3.5 \text{ in}$$

$$Nr2 = 22$$

$$RHX2 = 0.044 \text{ m}$$

$$Le2 = 6.144 \text{ m}$$

$$\text{drop2} = 2.025 \text{ psi}$$

$$i_{\max} = 1 \times 10^3$$

Compare to: $L(\text{dcthe}) = 6.64 \text{ m}$

$$dcthe = 14.097 \text{ mm}$$

$$dctheout = 0.016 \text{ m}$$

$$thct = 8.89 \times 10^{-4} \text{ m}$$

Heat transfer coefficient

$$h := \frac{Q}{\text{SurfaceHX} \cdot (T_{\text{H2in}} - T_{\text{H2out}})}$$

$$h = 0.17 \text{ K}^{-1} \frac{\text{watt}}{\text{cm}^2}$$

$$(T_{\text{H2in}} - T_{\text{H2out}}) = 1 \text{ K}$$

$$\text{SurfaceHX} = 0.294 \text{ m}^2$$

$$Q = 500 \text{ watt}$$

watt